

1 **CONTROLLING WASTEWATER TREATMENT PROCESSES**

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3 **Cross-Reference to Related Applications**

4 Benefit of international priority and internal priority is claimed under all
5 applicable international treaties and national laws throughout the world as
6 to the subject matter of U.S. Provisional Patent Applications Serial Nos.
7 60/412,817 and 60/479,150, respectively filed on September 24, 2002 and
8 June 18, 2003 in the names of David T. Redmon, Thomas E. Jenkins, Ian
9 Trillo Fox, Juan De Dios Trillo Monsoriu and Timothy D. Hilgart, attorney's
10 docket number 3085.004, and entitled **CONTROLLING WASTEWATER**
11 **TREATMENT PROCESSES.**

12 **Technical Field**

13 This invention relates to methods and apparatus for continuing,
14 automated control of biological wastewater treatment processes. In certain
15 preferred embodiments, it relates to control of aeration in suspended
16 growth biological treatment processes, especially in activated sludge
17 processes.

18 **Background of the Invention**

19 Most forms of biological processes for treatment of wastewater
20 involve introducing oxygen-containing gas into wastewater with some form
21 of energy- consuming apparatus. Generally, an electric motor is the energy

1 consumer, and it powers some kind of agitator, compressor or blower that
2 provides driving force to distribute the oxygen-containing gas in one or
3 more tanks containing wastewater. For many years it has been apparent
4 that the cost of electricity to operate such equipment is one of the largest,
5 and often the largest, operational cost of wastewater treatment plants.

6 In the early history of the art of biological treatment, process control
7 was "manual". Aided to an inadequate extent by visual observation and by
8 instrumentation that was usually limited and rudimentary, plant operating
9 personnel adjusted gas flow in an attempt to match that flow to the amount
10 of oxygen consumed in the biological process. Too much flow, overshoot,
11 wasted electricity. Too little, undershoot, impaired the quality of treatment.

12 As the art progressed, it was recognized that savings in electricity and
13 more consistent quality of treatment could be achieved with better and more
14 complete instrumentation. Then, it began to be apparent that major gains
15 in energy savings and quality could be attained through automatic control of
16 gas flows and other aspects of the processes.

17 Since at least as early as the 1960s, efforts at automated control of
18 the flow of oxygen-containing gas into biological wastewater treatment
19 processes have included measurements of the DO (dissolved oxygen) level
20 in the wastewater in the treatment tank. Gas flow is automatically reduced
21 if DO exceeds a predetermined target or set point and increased if DO falls
22 below the target. This mode of operation reduced but did not eliminate the
23 problem of overshoot and undershoot of the true oxygen and energy
24 requirements of the biological processes.

1 Since as least as early as the 1970s, the need to conserve energy
2 and tightening regulations on plant effluent quality have provided ample and
3 continuing motivation to develop better forms of automated control.
4 However, despite many suggestions for additional and/or other modes of
5 automatic control, in actual practice, control based primarily on DO levels,
6 with ensuing energy wastage and quality challenges, has remained quite
7 popular.

8 Present-day continuation of the popularity of control based primarily
9 on DO measurements, accompanied by wastefulness and quality problems,
10 suggests there is a long-felt, unsatisfied need for improvements in control of
11 biological processes for the treatment of wastewater. The present invention
12 seeks to fulfil this need.

13 **Summary of the Invention**

14 Our invention meets this need in a variety of ways. It includes both
15 methods and apparatus. Among these are methods of controlling a
16 biological wastewater treatment process and control system apparatus for
17 controlling a biological wastewater treatment process. These comprise a
18 number of different combinations of devices, steps and conditions, each of
19 which represents a particular aspect of what we have invented.

20 A first method aspect comprises, in at least one treatment tank
21 containing wastewater, conducting a biological process supported, at least
22 in part, by introducing oxygen-containing gas into the wastewater in the
23 form of bubbles provided in the wastewater by a gas supply system, and

1 causing at least a portion of the oxygen in said bubbles to dissolve in the
2 wastewater. At least a portion of the dissolved oxygen to be consumed by
3 the biological process, wherein the oxygen so dissolved may represent an
4 excess or a deficiency relative to the oxygen consumed by the biological
5 process, and wherein at least one gas collection member is positioned in
6 the treatment tank to receive offgas representing gas from said bubbles that
7 has not been dissolved into the wastewater. Operation of the biological
8 process is controlled with a control system that, as the process operates,
9 exercises continuing control over the process at least partially in response
10 to measurements that are taken by the control system from the offgas
11 collected in the gas collection member and that are correlative with the
12 amount of one or more gases in the offgas. The invention utilizes data
13 obtained through said measurements to provide, in the control system, for
14 the varying amounts of consumption of oxygen that occur in the biological
15 process, control values, or components of control values, that change in
16 response to, while remaining correlative with, such varying amounts of
17 oxygen consumption, and generating control signals based on the changing
18 control values or components.

19 A second method aspect comprises, in at least one treatment tank
20 containing wastewater, conducting a biological process comprising
21 suspended growth aeration. In this process, biological breakdown of
22 suspended and/or dissolved waste material present in the wastewater is
23 supported, at least in part, by introducing oxygen-containing gas into the
24 wastewater in the form of bubbles provided in the wastewater by a gas
25 supply system. These bubbles rise through at least a portion of the depth
26 of the wastewater in the direction of its upper surface, and cause at least a

1 portion of the oxygen in said bubbles to dissolve in the wastewater and at
2 least a portion of the dissolved oxygen to be consumed by the biological
3 process. The oxygen so dissolved may comprise an excess or represent a
4 deficiency relative to the oxygen consumed by the biological process. At
5 least one gas collection member is positioned to receive offgas
6 representing gas from said bubbles that has not been dissolved into the
7 wastewater. The method controls the operation of the process with a
8 control system that, as the process operates, exercises continuing control
9 over the introduction of wastewater into the process and/or over the
10 quantity of gas discharged into the tank through said gas supply system, at
11 least partially in response to measurements of the offgas, taken by the
12 control system, that are correlative with the amount of one or more gases in
13 the offgas. Data obtained through said measurements is utilized to provide,
14 in the control system, control values which are at least in part correlative
15 with changing needs for the supply of dissolved oxygen to the wastewater
16 as determined by the control system at least partly on the basis of such
17 data.

18 A third aspect, which is control system apparatus, comprises at least
19 one gas collection member that is positioned in at least one wastewater
20 processing tank in which the biological process is conducted, to collect from
21 the wastewater in the processing tank, offgas representing at least a portion
22 of oxygen-containing gas that has been introduced into but not dissolved in
23 the wastewater. There is at least one measuring device comprising at least
24 one gas detector that is connected with the gas collection member and that
25 can take measurements and thereby provide data indicative of the amount
26 of at least one gas in the offgas collected by the gas collection member.

1 There is also at least one controller connected with the measuring device,
2 which controller defines, for the varying amounts of consumption of oxygen
3 that occur in the biological process, control values, or components of
4 control values, that change in response to, while remaining correlative with,
5 such varying amounts of oxygen consumption, which controller generates
6 control signals based on the control values or components.

7 A fourth aspect involves apparatus of the type that comprises at least
8 one tank for conducting a biological process comprising suspended growth
9 aeration on wastewater, and a gas supply system for introducing oxygen-
10 containing gas into the wastewater in the form of bubbles and causing at
11 least a portion of the oxygen in said bubbles to dissolve in the wastewater
12 and at least a portion of the dissolved oxygen to be consumed by the
13 biological process. The oxygen so dissolved may comprise an excess or
14 represent a deficiency relative to the oxygen consumed by the biological
15 process. At least one gas collection member is positioned to receive offgas
16 representing gas from bubbles that have not been dissolved into the
17 wastewater. This apparatus has a control system comprising several parts.
18 there is at least one gas detector that can take measurements of the
19 amount of at least one gas collected in the gas collection member. There is
20 also at least one DO (dissolved oxygen) detector having a probe that, when
21 in contact with the wastewater in the tank, can take measurements of the
22 DO level of the wastewater. Also included is at least one controller that
23 contains or has access to code which the controller can utilize with said
24 measurements to provide, in the control system, control values which are at
25 least in part correlative with changing needs for the supply of dissolved
26 oxygen to the wastewater.

1 The foregoing general methods and apparatus may optionally be
2 practiced in any one or more of the following particular modes, which may
3 involve particularization of the general methods and apparatus and/or the
4 addition of steps or other features. The following optional modes, whether
5 employed singly or in any combination, represent not only preferred modes
6 of practicing the general methods and apparatus, but, when combined with
7 any of the general methods and/or apparatus, are also believed to be
8 inventions.

9 A number of these particular modes are applicable to each of the
10 general method and/or apparatus aspects and may be combined with any
11 or all other particular modes. Among these particular modes are those:

12 ... wherein the biological process comprises suspended growth
13 aeration which includes biological metabolism of suspended and/or
14 dissolved waste material present in the wastewater is supported, at least in
15 part, by the oxygen-containing gas introduced into the wastewater;

16 ... wherein the biological process is a continuous flow process;

17 ... wherein the biological process is an activated sludge process;

18 ... wherein the control system is programmed to tend to maintain a
19 positive DO level in at least a portion of the tank;

20 ... wherein said gas collection member is positioned at a surface of
21 the wastewater;

22 ... comprising a tank having a wastewater inlet and an outlet, and the
23 control system includes DO measuring devices at first and second locations
24 in the tank, the first location being closer to the inlet than to the second
25 location, or the second location being closer to the outlet than to the first
26 location;

1 ... wherein the first location is closer to the gas collection member
2 than to the second location, or the first location is adjacent the inlet and the
3 second location is adjacent the outlet; or the gas collection member and the
4 first location are each closer to the inlet than to the second location, or the
5 gas collection member and the second location are each closer to the outlet
6 than to the first location, or the gas collection member is positioned
7 between the first and second locations;

8 ... comprising an elongated tank having upstream and downstream
9 halves;

10 ... comprising an elongated tank divided into at least two sections by a
11 baffle and/or other form of length divider, and at least one of said sections
12 has upstream and downstream halves;

13 ... wherein a gas collection member is positioned in an upstream half
14 of a tank or tank section to receive offgas representing gas from bubbles
15 that have not been dissolved in the wastewater;

16 ... wherein the control system includes at least two DO probes
17 respectively positioned in upstream and downstream halves of a tank or
18 tank section for gathering data with respect to DO levels;

19 ... comprising a tank or tank section having an upstream end, and at
20 least portions of the gas collection member and of a DO probe positioned in
21 the upstream half of the tank are respectively within about the first 10% or
22 15% or 20% of the length of the tank, measured from the upstream end;

23 ... wherein measurements of the offgas taken by the control system
24 are correlative with the amount of at least one gas representing at least a
25 portion of the composition of the offgas;

26 ... wherein the oxygen-containing gas is or comprises air and
27 measurements of the offgas taken by the control system are correlative with

1 the amount of oxygen or the amount of carbon dioxide or the amounts of
2 oxygen and carbon dioxide in the offgas;
3 ... wherein a controller contains or has access to code, and optionally
4 also tables of data, with the aid of which it defines said control values;
5 ... wherein the system operates as a feed forward controller where
6 control outputs are generated, at least in part, based on requirements
7 control values and performance control values;
8 ... wherein said control values are requirements control values;
9 ... wherein said control values comprise requirements control values;
10 ... wherein the control values comprise requirements control values
11 correlative with the oxygen consumed by the biological process, as
12 determined by the control system;
13 ... wherein said control values comprise DO control values correlative
14 with changing amounts of oxygen-containing gas required to return the DO
15 level in the wastewater to a target value;
16 ... wherein said control values comprise performance control values
17 correlative with variations in the ability of the gas supply system to transfer
18 oxygen to the wastewater;
19 ... wherein said control values comprise requirements control values
20 combined with DO control values;
21 ... wherein said control values comprise requirements control values
22 combined with DO rate of change values and DO control values;
23 ... wherein said control values comprise requirements control values
24 combined with performance control values;
25 ... wherein the control system comprises at least one gas quantity
26 regulating apparatus which, in response to control inputs from the control
27 system, changes or maintains the quantity of gas introduced into the

1 wastewater;

2 ... wherein the control system comprises at least one liquid flow
3 regulating apparatus which, in response to control inputs from the control
4 system, changes or maintains the quantity of wastewater introduced into
5 the tank; and

6 ... comprising at least first and second tanks, the second of which is
7 controlled simultaneously with the first tank, or which is controlled
8 independently from the first tank.

9 A number of the particular modes are applicable to each of the
10 general method aspects and may be combined with any or all of the other
11 particular modes. Among these particular modes are those:

12 ... wherein said excess or deficiency manifests itself as an increase or
13 decrease in the DO (dissolved oxygen) level of the wastewater;

14 ... comprising providing OP (operational performance) data in the
15 control system;

16 ... comprising providing PS (performance standard) data in the control
17 system;

18 ... comprising providing RSP (relative system performance) data in
19 the control system that is derived at least in part with PS data;

20 ... comprising: (A) causing the control system to take, at one or more
21 locations in the wastewater, continuing measurements that are correlative
22 with DO levels in the wastewater differing positively and/or negatively from
23 a target DO value; (B) generating, in the control system, DO control values
24 of magnitude sufficient, when applied in conjunction with requirements
25 control values, to at least partially offset deviations of DO level in the
26 wastewater from the target DO value;

1 ... wherein the control system generates DO control values correlative
2 with the amount of oxygen required to move the DO level in the wastewater
3 to the target DO value;

4 ... wherein: (A) within at least one tank, the wastewater flows along a
5 flow path that has upstream and downstream portions, (B) a gas collection
6 member is positioned along the upstream portion to receive offgas
7 representing gas from bubbles that have not been fully dissolved in the
8 wastewater, (C) data with respect to DO level is gathered from at least two
9 DO probes respectively positioned along the upstream and downstream
10 portions of the flow path; (D) the control system establishes, on a continuing
11 basis, control values for the entire tank that are at least in part correlative
12 with a combination of (1) changing consumption of oxygen by the biological
13 process, as measured with the aid of said gas collection member and (2)
14 said DO level data gathered from the DO probes positioned along the
15 upstream and downstream portions of the flow path;

16 ... wherein: (A) the control system establishes, on a continuing basis,
17 control values that are at least in part correlative with a combination of (1)
18 changing consumption of oxygen by the biological process, as measured
19 with the aid of said gas collection member and (2) deviations, from a first
20 target value, of the DO level measured by a DO probe positioned along an
21 upstream portion of the wastewater flow path, and (B) the control system
22 adjusts said first target value, on a continuing basis, with the aid of data
23 correlative with deviations, from a second target value, of the DO level
24 measured by a DO probe positioned along a downstream portion of the flow
25 path;

26 ... wherein the wastewater flows in plug flow;

27 ... wherein the wastewater flows along a flow path having a

1 dimension in the direction of wastewater flow that is greater than its
2 average dimension perpendicular to such direction;

3 ... wherein: (A) data with respect to the rate of change of DO level is
4 gathered from at least one DO probe positioned in the tank, and (B) the
5 control system establishes, on a continuing basis, control values which are
6 applied to a tank as a whole, said control values being at least in part
7 correlative with a combination of (1) changing consumption of oxygen by
8 the biological process, as measured with the aid of the gas collection
9 member along an upstream portion of a wastewater flow path through the
10 tank (2) DO level data gathered from at least two DO probes respectively
11 positioned along upstream and downstream portions of the flow path and
12 (3) DO rate of change data;

13 ... comprising: (A) causing the control system to take, at one or more
14 locations in the wastewater, continuing measurements that are correlative
15 with DO levels in the wastewater differing positively and/or negatively from
16 one or more target DO values; (B) causing the control system to take, at
17 one or more locations in the wastewater, continuing measurements that are
18 correlative with rates of change of DO level in the wastewater; and (C)
19 generating in the control system, on a continuing basis, control values that
20 are at least in part correlative with a combination of the consumption of
21 oxygen in the biological process, of said DO levels and of said rates of
22 change;

23 ... comprising: (A) causing the control system to establish, on a
24 continuing basis, performance values that are correlative with the ability of
25 the gas supply system to dissolve said oxygen containing gas in the
26 wastewater, and (B) causing the control system, on a continuing basis, to
27 combine said performance values with requirements control values which

1 are at least in part correlative with changing consumption of oxygen in the
2 biological process;

3 ... comprising generating, in the control system on a continuing basis,
4 RSP control values correlative with relationships between (A) OP data,
5 generated by the control system, correlative with the varying ability of the
6 gas supply system to transfer oxygen to the wastewater under fluctuating
7 process conditions, comprising one or more of gas supply system
8 conditions, wastewater conditions, process conditions, and atmospheric
9 conditions, and (B) PS data, provided in the control system, correlative with
10 the ability of the gas supply system to transfer oxygen to water and/or
11 wastewater under predetermined standards for said conditions;

12 ... wherein the control values are established at least in part with OP
13 data which are provided in the control system and which is based on one or
14 more of the following: gas supply system conditions, wastewater conditions,
15 process conditions, and atmospheric conditions, and wherein said
16 condition/conditions, including characteristics of any of the foregoing, is/are
17 determined by the control system;

18 ... wherein the control values are established at least in part with PS
19 data that includes OTR : Q (oxygen transfer rate : flow) data correlative with
20 oxygen transfer rates which the gas supply system could achieve in clean
21 water at varying rates of flow of gas through the gas supply system;

22 ... wherein the control values are established at least in part with
23 apparent alpha values which are correlative with a ratio between (a) the
24 rate, as determined by the system, at which the gas supply system can
25 transfer oxygen to the wastewater and (b) the rate at which the gas supply
26 system can transfer oxygen to clean water;

27 ... comprising: (A) providing, in the control system, OTR : Q (oxygen

1 transfer rate : flow) control values correlative with oxygen transfer rates
2 which the gas supply system could achieve in clean water at varying rates
3 of flow of gas through the gas supply system; (B) providing, in the control
4 system, apparent alpha values which are correlative with a ratio between
5 (a) the rate, as determined by the system, at which the gas supply system
6 can transfer oxygen to the wastewater and (b) the rate at which the gas
7 supply system could transfer oxygen to clean water; and (C) deriving RSP
8 values by combining OTR : Q and apparent alpha values;

9 ... wherein apparent alpha values are determined at least in part by
10 the control system and reflect changes in the condition of the gas supply
11 system and the wastewater that can affect the amount of oxygen which the
12 gas supply system can transfer to the wastewater;

13 ... wherein control values are applied by the system based at least in
14 part on process control needs comprising at least one form of process
15 control needs selected from among process oxygen control needs, DO
16 level control needs, and performance control needs and wherein the
17 applied control value is within plus or minus 20%, more preferably 10%, still
18 more preferably 5% and most preferably 3%, based on the data available in
19 the system at the time the applied control value is applied, of a reference
20 control value which would produce a flow rate of gas and/or wastewater into
21 the biological process that would precisely satisfy the particular need or
22 needs;

23 ... wherein control values are applied by the system based at least in
24 part on process control needs comprising at least one form of process
25 control needs selected from among process oxygen control needs, DO
26 level control needs, and performance control needs and wherein the control
27 values are applied directly or indirectly to at least one flow regulating device

1 to provide on a continuing basis control inputs to said device to cause said
2 device to change or maintain the quantity of gas introduced into the
3 wastewater and/or to change or maintain the quantity of wastewater
4 introduced into the tank;

5 ... wherein control is effected, at least in part, using data on rates of
6 change of DO level in the tank over one or more predetermined time
7 periods;

8 ... wherein the control system derives control inputs based at least in
9 part (1) on differences between (a) the actual wastewater temperature and
10 (b) a selected reference temperature, and/or (2) on differences between (a)
11 the actual barometric pressure acting on the wastewater surface and (b) a
12 selected reference barometric pressure;

13 ... wherein the control system exercises control at least partially in
14 response to measurements correlative with OUR (oxygen uptake rate), or
15 OTR (oxygen transfer rate), or OTE (oxygen transfer efficiency), or any
16 combination thereof; and

17 ... wherein the control system derives control inputs by adjusting the
18 control values at least in part with respect to the control response
19 characteristics of a flow regulating device;

20 A number of the particular modes are applicable to each of the
21 general apparatus aspects and may be combined with any or all other
22 particular modes. Among these particular modes are those:

23 ... wherein the control system comprises at least one of the following:
24 a device for measuring wastewater temperature; a device for measuring
25 gas flow from the gas collection member; a device for measuring the
26 dissolved oxygen content of the wastewater; and a device for measuring

1 oxygen content in the offgas;

2 ... wherein the control system comprises a device for measuring
3 wastewater temperature, a device for measuring gas flow from the gas
4 collection member, a device for measuring the dissolved oxygen content of
5 the wastewater, and a device for measuring oxygen content in offgas;

6 ... comprising code that defines, on a continuing basis, RSP (relative
7 system performance) control values correlative with relationships between
8 (A) OP (operational performance) data correlative with the varying ability of
9 the gas supply system to transfer oxygen to the wastewater under
10 fluctuating process conditions, comprising one or more of gas supply
11 system conditions, wastewater conditions, process conditions, and
12 atmospheric conditions, and (B) PS (performance standard) data correlative
13 with the ability of the gas supply system to transfer oxygen to water and/or
14 wastewater;

15 ... comprising code that defines OP data;

16 ... that includes or has access to PS data;

17 ... comprising code that defines RSP data at least in part with PS data
18 that is stored in the control system;

19 ... wherein PS data is stored in the system and includes OTR : Q
20 (oxygen transfer rate : flow) data correlative with oxygen transfer rates
21 which the gas supply system could achieve in clean water at varying rates
22 of flow of gas through the gas supply system;

23 ... wherein at least one control element is connected with the
24 controller and is responsive to the control signals generated in the controller
25 to effect control over at least a portion of the biological process by adjusting
26 at least one parameter of the process;

27 ... which further includes one or more liquid flow control units that can

1 control introduction of wastewater into the tank;
2 ... which further includes one or more gas flow control units that can
3 control the introduction of gas discharged into the tank through said gas
4 supply system; and
5 ... further comprising at least one gas quantity regulating apparatus
6 capable of changing or maintaining the quantity of gas introduced into the
7 wastewater, in response to control inputs by the control system including
8 inputs based at least in part on requirements control values and DO control
9 values, wherein the requirements control values and the DO control values
10 are based at least in part on relationships with RSP values.

11 **Advantages**

12 Some embodiments of the present invention measure oxygen
13 consumption and the performance parameters of the aeration system. This
14 provides an opportunity for "predictive" (or feed forward) control where the
15 required controlled variable (e.g., air flow rate) can be predicted based on
16 oxygen consumption and equipment performance. It is believed that, in
17 practice, prior art control systems have almost exclusively been "reactive"
18 (feedback). These prior systems react to errors in process performance,
19 and errors are thus an inherent result of certain prior control systems'
20 performance. Because of the errors generally inhering in feedback systems
21 the biological activity of microorganisms in processes operated under this
22 mode of control can be compromised by fluctuations in the dissolved
23 oxygen level. With preferred embodiments of our invention, the variables
24 critical to biological activity can be made more stable, resulting in reduced
25 effluent variations.

1 To minimize the deleterious impact of errors in prior systems, there is
2 a tendency for operators to set the target dissolved oxygen level at a value
3 higher than the minimum level which would be acceptable in a well-
4 controlled operation. This provides a "cushion" to prevent excursions in
5 loading from causing excessive decrease in the dissolved oxygen level.
6 Because the operation of certain preferred embodiments of our system can
7 be more stable and errors can be minimized or eliminated, the target level
8 of dissolved oxygen can be set lower. This can produce higher efficiency
9 and result in significant savings in energy and other associated costs.

10 Pumping and the time required for reactions to occur in systems that
11 withdraw liquid samples, such as most respirometric techniques, result in a
12 time delay between the beginning of the measurement process and
13 obtaining the results. Because of the construction of preferred
14 embodiments of our invention, it is possible to capitalize on the speed of
15 fast measurement devices leading to near or true "real time" determination
16 of the oxygen requirements and performance of the process.

17 Some preferred embodiments of our invention monitor the impact of
18 changes in oxygen consumption in real time. These embodiments afford
19 an opportunity to detect slug loading or inhibitory contaminants from
20 industrial contributors or other sources. The rapid response of these
21 embodiments will minimize the impact of these changes on the effluent
22 quality and alert the operator so proper corrective measures can be
23 implemented.

1 Some existing systems measure the oxygen demand of the
2 wastewater. Contrary to what is common in prior practice, certain
3 embodiments of the invention can measure the performance of the aeration
4 equipment (i.e. diffusers) on a continuing basis and even in real time.
5 These measured parameters may for example include oxygen transfer
6 efficiency and alpha (ratio of actual process to clean water performance).
7 The present control system can apply apparent alpha values, determined
8 by the control system, that reflect changes in the condition of the gas supply
9 system and the wastewater that can affect the amount of oxygen which the
10 gas supply system can transfer to the wastewater. This information
11 provides insights into actual aeration system performance and affords an
12 opportunity to monitor degradation of the system over time due to fouling
13 and/or other forms of degradation of aerator performance. Cleaning or
14 replacement of diffusers can be optimized based on actual performance,
15 minimizing the costs of premature or unduly delayed cleaning or
16 replacement, thus permitting cleaning before performance and energy
17 efficiency is significantly degraded.

18 In the tuning of certain prior systems, system response to errors and
19 load changes is monitored and the parameters affecting response are
20 modified by empirical results derived from observation and experience. For
21 example, this is true of certain "PID" (Proportional-Integral-Derivative)
22 control algorithms, but it is also generally true of feedback control
23 algorithms. Changes in aeration system condition, incoming waste and
24 ambient conditions required modification of the tuning parameters.
25 Because in certain of its preferred embodiments our system's response is
26 based on the physical configuration of the process equipment and a

1 combination of known and measured aeration system effectiveness, the
2 tuning is insensitive to changes in aeration system condition, incoming
3 waste and atmospheric conditions.

4 Once data on the physical configuration and aeration system
5 performance is stored, these embodiments can predict the response to the
6 above-mentioned changes by mathematical calculations based on known
7 performance parameters.

8 Certain prior control systems have used "lumped parameter" tuning,
9 where the effects of process loading, biological performance and aeration
10 system performance are not differentiated in determining the response of
11 the system to perturbations. A change in process parameters required a
12 change in the tuning of the control system. With certain embodiments of
13 our control system process parameters related to process loading,
14 biological performance and aeration system performance are individually
15 monitored, making such systems both more responsive and more stable.

16 A number of existing methods used to measure oxygen requirements
17 of a treatment system, such as most respirometric techniques (also referred
18 to as respirometry), involve movement of samples of the contents of the
19 aeration tanks to a reaction cell. In many systems additional chemicals
20 must be used to determine the oxygen requirements of the wastewater.
21 The pumping and fluid handling systems are prone to plugging and require
22 significant maintenance. The additional chemicals, if required, are an
23 additional cost of operation. Because preferred embodiments of our
24 invention use gas leaving the surface rather than withdrawn liquid samples,

1 it is not prone to such plugging and maintenance is minimized. Reliability is
2 also enhanced.

3 All embodiments of the invention, whether specifically disclosed
4 herein or not, will not necessarily have all of the above advantages, nor the
5 same combinations of advantages. Moreover, users of the invention,
6 manufacturers of components or complete systems involving the invention
7 and other persons skilled in the art may identify, with the aid of the present
8 disclosure and/or through experience with the invention, embodiments that
9 inherently include advantages not discussed above.

10 **Brief Description of the Drawings**

11 Figures 1-4 are each schematic diagrams of biological wastewater
12 treatment processes and components of control systems according to the
13 invention.

14 Figure 5 is a flow sheet illustrating the data entry functions and
15 control logic functions of software useful in practicing the invention.

16 **Various and Preferred Embodiments**

17 **Introduction**

18 In general, our control method and apparatus are useful with a wide
19 variety of biological wastewater treatment processes. Typically, these are
20 processes in which aeration with oxygen-containing gas supports the

1 metabolizing of waste by bacteria in the wastewater, e.g., activated sludge
2 processes, in one or more tanks. Other gases or vapors may be used in or
3 in connection with these processes for any suitable purpose, e.g., cleaning
4 gas.

5

6 Our control system employs any form of measurement apparatus to
7 receive data on one or more process parameters, which may include any
8 parameters of or affecting the process. Such parameters include varying
9 amounts of one or more gases in offgas recovered from the wastewater in
10 the tank, and may include, for example, other gas and liquid flows, water
11 temperature, atmospheric pressure and other variables. Measurements of
12 these parameters may be made by any suitable kind(s) of measurement
13 devices. They are connected with, and are used to furnish needed data on
14 process parameters to, a controller.

15

16 The data outputs of the measurement devices to the controller,
17 whether in electrical or other form, need not correspond directly, e.g., be
18 numerically proportional with, measured parameters expressed in
19 customary units. However, for at least some measurements of interest,
20 measurement devices are available that give outputs corresponding directly
with measured parameters, and these devices are preferred.

21

22 The controller employs the data outputs to establish varying control
23 values correlative with, among a variety of possibilities, one or more varying
24 process needs for oxygen. These include requirements control values, and
25 may also include DO control values and/or performance control values.
How this is accomplished can depend to some extent on the nature of the

1 measurement device outputs and/or the capabilities of the controller.

2 Whether the data outputs do or do not directly correspond with the
3 measured parameters, the controller may for example contain or have
4 access to, and derive any of the control values from, a table which contains
5 and matches data output values with appropriate, precalculated control
6 values. On the other hand, the controller may calculate any of the control
7 values from algorithms, as data is received, where directly corresponding
8 data outputs are available to it for the parameters needed in the calculation.
9 Calculation of control values as data is received is also possible if directly
10 corresponding data outputs are not available to the controller, for example
11 when it contains or has access to means for converting those data outputs
12 to a form useful in such calculations. Detailed information on calculation of
13 control values is provided below.

14 Varying control values, present in the controller, are used, with or
15 without adjustment, to provide control signals in the controller. Any suitable
16 kind of automated control element(s), such as control valves, weirs, motor
17 controls and other devices, is/are connected with the controller, which
18 transmits the control signals to them. The signals may be the control
19 values themselves or may differ from them. For example, the control
20 values may have been adjusted in generating control signals , e.g., to
21 conform with signal requirements of the control elements or with such
22 factors as the operational characteristics of those elements, of the gas
23 supply system or of the process.

1 Preferably, the control values directly correspond numerically with the
2 process need or needs to which the control values relate, and the signals
3 have adjusted magnitudes which provide some selected increment of the
4 control action required by the control values and the related need. Then, as
5 the system takes continuing measurements of process parameters affected
6 by the incremental control action, the control values may remain the same
7 or be changed by the controller as a result of observation of the effects of
8 the control action applied and/or of other factors. Further control signals of
9 the same or different magnitude as previous ones may then be issued to
10 the control element(s) to continue the control action in increments for
11 satisfying the then current control values.

12 Separate control signals may be issued by a controller or controllers,
13 separately representing different kinds of control values. For example,
14 varying, separate signals may be transmitted to separate, plural gas supply
15 control elements, which signals are respectively based on varying
16 requirements control values and varying DO control values. Then, based
17 on the separate control signals the separate control elements can supply
18 separate, regulated flows of gas from separate gas supply lines. These
19 flows can enter a treatment tank as separate flows or, after having been
20 combined with each other upstream of the tank but downstream of the
21 control elements, as a single flow. The aggregate amount of these
22 separate flows, whether entering the tank in the form of single or plural
23 flows, can be in an amount sufficient to meet the varying needs for oxygen
24 to metabolize, and, optionally, to otherwise treat, waste in the wastewater
25 and to maintain a substantially stable DO level.

1 However, the controller preferably generates varying control values of
2 which two or more different kinds of control values are component parts,
3 such as a combination of varying requirements control values and varying
4 DO control values. Then, the controller may, if desired, generate varying
5 control signals correlative with a varying combination or total of the different
6 control value components. These signals may if desired be transmitted to a
7 single control element. In turn, such a control element may if desired cause
8 a single gas line, or a combined set of gas lines, to provide gas to the
9 wastewater in the amounts needed.

10 When, as preferred, the varying control values used to generate
11 control signals include as component parts requirements control values, DO
12 control values and performance control values, gas may then be supplied in
13 the varying amounts required to meet the need for oxygen to metabolize or
14 otherwise treat waste, suitably adjusted to maintain stable DO levels and
15 account for performance changes. Performance changes may for example
16 involve one or more of the following: gas supply system conditions, e.g., the
17 results of diffuser fouling, diffuser cleaning or changes in gas supply rates
18 and the resulting changes in diffuser flux rate where area-release fine
19 bubble diffusers are involved; changes in wastewater conditions; variations
20 in process conditions, and changing atmospheric conditions. Such
21 condition/conditions, including characteristics of any of the foregoing, is/are,
22 or may be, as determined by the control system.

23 Whatever the nature and mode of use of the control values and
24 control signals, the control system causes the control elements to act in
25 response to those signals for effecting control over the biological process.

1 The control system may effect control over the biological process in any
2 way that is effective in matching the availability of oxygen-containing gas to
3 the changing consumption of or need for oxygen in all or a portion of the
4 process, and possibly for meeting other needs.

5 Examples of ways of effecting control over the process include one or
6 more of the following: turning up or turning down the flow of gas and/or
7 wastewater to the process, changing the distribution of gas introduced into
8 the system, changing the quantity or distribution of wastewater in the tank,
9 e.g. as in step feeding, changing the operating intensity of mechanical or
10 brush aerators, turning at least a portion of the mechanical or brush
11 aerators and/or diffusers that are available in the system on or off, feeding
12 zero or varying amounts of supplemental oxygen to the process, and
13 altering the oxygen transfer efficiency of the operation, such as by changing
14 the distance traversed by gas bubbles as they pass through the
15 wastewater, e.g., by turning agitators on, up, down or off and/or altering the
16 wastewater depth in a given tank. Control elements will be selected that
17 are suitable for the chosen way(s) of effecting control over the process.

18 The following discussions and Figures 1-5 present several specific,
19 illustrative embodiments of wastewater treatment apparatus, control system
20 apparatus and software that are useful in the invention.

21 **Detailed Description of the Drawings**

22 Figures 1-4 schematically illustrate exemplary biological process
23 equipment including tanks and means for introducing oxygen-containing

1 gas into wastewater in the tanks. These figures also illustrate control
2 system arrangements that are compatible with the process equipment
3 layouts and that include measuring apparatus to derive data and controllers
4 to derive control inputs for the process. Figure 5 schematically illustrates
5 one example of many possible arrangements of functions within the
6 process and particularly within software that skilled programmers can
7 design for use in controllers carrying out the present invention, such as the
8 embodiments of Figures 1-4.

9 **Figure 1**

10 The embodiment of Figure 1 includes tank 2 which contains
11 wastewater in which a suspended growth aeration process is being
12 conducted. Inlet 17 and outlet 18, respectively, are provided for entry of
13 wastewater to be aerated in the tank and discharge of mixed liquor to
14 subsequent processes.

15 In and around the tank are components of a gas supply system.
16 Among these are plural devices 3 of any suitable type for introducing
17 oxygen-containing gas bubbles into the wastewater, e.g., fine bubble
18 diffusers, a source of gas 4, which is shown as a pipe but could be another
19 device and gas flow regulating device 1, which is shown as a valve, but
20 could be another device.

21 In the process, which may aerate the wastewater continuously or
22 intermittently, bubbles of oxygen-containing gas, generated by the gas
23 supply system, rise through at least a portion of the depth of the wastewater

1 in the direction of its upper surface. Oxygen in the bubbles dissolves in the
2 wastewater. At least a portion of the dissolved oxygen is consumed by the
3 biological process . The oxygen so dissolved may comprise an excess or
4 represent a deficiency relative to the oxygen consumed by the biological
5 process. Such excess or deficiency may manifest itself as an increase or
6 decrease in the DO (dissolved oxygen) level of the wastewater.

7 A control system according to the invention controls the aeration
8 process. In this embodiment, it includes a device 5, for measuring
9 wastewater temperature, a gas collection member, e.g., a hood 10 for
10 collecting gas escaping from the tank, a device 11 for measuring gas flow
11 from the hood, a device 12 for measuring the dissolved oxygen content of
12 the wastewater, a device 13 for measuring oxygen content in offgas, a
13 controller 14 for automatically executing control logic, connections 15 for
14 transmitting measured values to the controller and control signals from the
15 controller and an outlet 16 for discharging sample air to the atmosphere.

16 In the embodiment illustrated in Figure 1 hood 10 represents a
17 location from which to obtain data useful to determine the estimated oxygen
18 transferred by the gas supply system. Probe 12 represents a location from
19 which to obtain data to determine the estimated DO level in the tank.
20

21 From this data, controller 14 establishes corresponding requirements
22 control values which are correlative with the oxygen transferred by the gas
23 supply system and the rate of increase/decrease of DO, as determined by
24 the control system. Controller 14 also establishes DO control values
25 correlative with the oxygen adjustment required, as determined by the

1 control system, to return DO levels to a target value. Preferably, the
2 establishment of requirements control values is at least partially in response
3 to measurements correlative with the OUR (oxygen uptake rate) of the
4 wastewater, or the OTR (oxygen transfer rate) of the gas supply system, or
5 the OTE (oxygen transfer efficiency) of the gas supply system, and
6 preferably some combination of these.

7 Preferably, the requirements control values correlative with the
8 oxygen consumed by the biological process, as determined by the control
9 system, are combined with DO control values. The controller combines
10 these two kinds of control values, whether additive or offsetting to some
11 extent, and from this total establishes control values and corresponding
12 control signals that, with or without adjustment, e.g., to account for the
13 response characteristics of the valve actuator, are transmitted by controller
14 to gas flow regulating valve 1. Where the process is a continuous flow
15 process, the combination of control values generated by the control system
16 may be correlative with a combination of rates of oxygen consumption and
17 rates of change of DO level in the tank over one or more predetermined
18 time periods. Typically, the control system is programmed to tend to
19 maintain a stable, positive dissolved oxygen level in at least a portion of the
20 tank, while meeting the varying oxygen needs of the biological process.

21 The selected locations for the hood and probe may be arbitrary if the
22 tank contents are substantially completely mixed and homogenous, or, if
23 not, may be locations of specific interest to the operator.

1 **Figure 2**

2 Here again, a control system according to the invention controls the
3 aeration process in a plural tank aeration operation. In common with the
4 Figure 1 embodiment, this embodiment has a first tank 23 which contains
5 wastewater in which a suspended growth aeration process is conducted.
6 Inlet 78 and outlet 79, respectively, are present for entry of wastewater into
7 the tank and discharge of mixed liquor.

8 In and around this tank are components of a gas supply system.
9 Among these are a source of gas 25, which is shown as a pipe but could be
10 another device, and plural devices 24 of any suitable type for introducing
11 oxygen-containing gas bubbles into the wastewater.

12 The Figure 2 embodiment includes a second aeration tank 45 which
13 contains wastewater undergoing suspended growth aeration. Inlet 78 and
14 outlet 79, respectively, are provided for entry and discharge of wastewater
15 and mixed liquor.

16 Blower or compressor 75 supplies air or gas to tank 45 and optionally
17 to one or more additional tanks. Plural devices 24 of any suitable type are
18 present in tank 45 and are connected to the blower for introducing oxygen-
19 containing gas bubbles into the wastewater.

20 There are three sampling lines 41, 42 and 43. They respectively
21 include certain auxiliary devices, discussed below. Lines 41 and 42 draw
22 gases from the hoods 32, which are part of measurement apparatus to be

1 discussed further below, to determine requirements control values for the
2 tanks 23 and 45. Hood 32 of tank 45 has a flotation device 46 to maintain
3 the hood at the wastewater surface during water level variations. Line 43
4 and its auxiliary devices draw ambient air from the atmosphere through
5 intake 39 for calibrating and verifying the accuracy of the measurement
6 apparatus.

7 Auxiliary devices present in all three sampling lines include
8 compressors 49 to provide positive flow of offgas from the hoods 32
9 through the sampling lines to the measurement apparatus for analysis,
10 pressure relief valves 50 to prevent build-up of excessive pressure in the
11 lines, drying devices 55 to remove entrained water and water vapor from
12 the gas in the lines prior to its entry into the measurement apparatus and
13 valves 56, which may be other kinds of devices. These valves control the
14 direction of gas and/or gas flow in proper sequence from various tanks to
15 the measurement apparatus and/or to the atmosphere.

16 Optionally, several additional system elements may be provided. For
17 example, line 42 may have a discharge conduit 47 to release excess gas
18 from the hood 32 of tank 45 into or adjacent to the wastewater and heating
19 system 48 to prevent condensation of water vapor. Lines 57 may provide
20 entrances for gas from other hoods or tanks into line 42 and the
21 measurement apparatus.

22 Some elements of the measuring apparatus of this embodiment of the
23 control system are arranged along analysis line 44. Device 65 detects
24 moisture or condensate in offgas or ambient gas flow. Device 68 measures

1 gas temperature, while device 67 measures gas pressure. Device 66
2 measures carbon dioxide content in the offgas. Restriction 64 throttles gas
3 flow to create positive pressure in the measurement system. Device 35
4 measures oxygen content in offgas, while outlet 38 discharges used sample
5 air to the atmosphere.

6 Other elements of the measuring apparatus include devices 26 in
7 each tank, for measuring wastewater temperature, the above-mentioned
8 hoods 32 for collecting gas escaping from the tanks, a device 33 in tank 23
9 for measuring gas flow from the hood, device 74 for measuring gas flow into
10 tank 45 and device 34 in each tank for measuring the dissolved oxygen
11 content of the wastewater.

12 In the embodiment shown in Figure 2 the arrangement in tank 23
13 differs from the arrangement in tank 45 in the technique employed for
14 measuring the gas flow to the respective tanks. In tank 23 device 33 is
15 used for measuring the gas flow escaping from the hood, and this gas flow
16 rate is extrapolated to encompass the entire gas flow to the tank by the ratio
17 of the hood surface area to the area of the entire tank. In tank 45 device 74
18 is used for measuring the gas flow to the entire tank directly. Factors
19 bearing on deciding which arrangement to use in a given tank include the
20 extent of any variation in the process from one location to another within the
21 tank, and the nature of existing instrumentation associated with the tank
22 when converting to the use of the present invention. As the figure shows,
23 these two arrangements may be used in different tanks of the same plant or
24 may be used in combination with each other within the same tank.

1 With the aid of data from the measuring apparatus a controller 36
2 automatically executes control logic for each tank. Interface device 76 is
3 provided to display measured and calculated data and to assist in entering
4 constants and control parameters for operating the system. Connections
5 37 transmit measured values to the controller and control signals from the
6 controller for tanks 23 and 45. Through signals sent via these connections
7 the controller adjusts the gas flow to tank 23 with gas flow regulating device
8 22, which is shown as a valve, but could be another device, and adjusts gas
9 flow to tank 45 by altering the speed of blower 75. Connections 58 transmit
10 measured values from other measurement apparatus to the controller and
11 control signals from the controller for other hoods or tanks, where such are
12 provided.

13 As shown by Figure 2 and the above discussion, each of tanks 23
14 and 45 has one point of gas flow entry and control. As in Figure 1, each
15 hood 32 represents a location from which to obtain data useful to determine
16 the varying amounts of oxygen transferred by the gas supply system for
17 each tank.

18 First tank 23 has a DO sensor, device 34, located at the upstream
19 end of the tank. Second tank 45 has first and second DO sensors, devices
20 34 and 77, located respectively at the upstream and downstream ends of
21 that tank. The DO sensors, whether or not single or dual sensors are used
22 in the second tank, provide data on a continuing basis concerning varying
23 DO levels in their respective tanks. Such data is useful to provide DO rate
24 of increase/decrease data and to determine DO control values that are
25 correlative with the varying oxygen adjustment required, as determined by

1 the control system, to return DO levels to a target value.

2 From this data, controller 36 establishes, individually for each tank,
3 requirements control values which are based on the oxygen transferred by
4 the gas supply system and the rate of DO increase/decrease, in the
5 respective tanks, as determined by the control system. From a combination
6 of the requirements control values and the DO control values for each tank,
7 controller 36 establishes separate and varying gas rates and corresponding
8 control signals that will satisfy varying and differing needs for oxygen in the
9 respective tanks. These separate signals are sent to gas flow regulating
10 device 22 and to blower 75 as required to meet such needs. The
11 calculations for each tank may be performed sequentially or simultaneously
12 in a single controller or may be performed in a separate controller for each
13 tank.

14 **Figure 3**

15 In common with Figure 1, the embodiment of Figure 3 has a tank 91
16 which contains wastewater in which a suspended growth aeration process
17 is being conducted. Inlet 156 and outlet 157, respectively, are provided for
18 entry of wastewater to be aerated in the tank and discharge of mixed liquor.
19 The tank has at least two distinct zones in which gas flow may be controlled
20 independently. Here again, a control system according to the invention
21 controls the aeration process.

22 In and around the first control zone of tank 91 are components of a
23 gas supply system. Among these are plural devices 92 of any suitable type

1 for introducing oxygen-containing gas bubbles into the wastewater, a
2 source of gas 93, which is shown as a pipe but could be another device and
3 gas flow regulating device 90, which is shown as a valve, but could be
4 another device. The gas supply system of the second control zone of the
5 tank is also served by the gas source 93 and is provided with a gas flow
6 regulating device 95 and plural devices 96 introducing oxygen-containing
7 gas bubbles into the wastewater.

8 The first control zone of the tank, in common with Figure 1, includes a
9 device 94, for measuring wastewater temperature, a gas collection
10 member, e.g., a hood 110, for collecting gas escaping from the tank, and a
11 sampling line 122. Arranged along sampling line 122 are measuring
12 devices and several auxiliary items, discussed below, and a device 111, for
13 measuring gas flow from the hood.

14 Associated with the second control zone are a device 97, for
15 measuring wastewater temperature, a hood 118, for collecting gas
16 escaping from the tank, and a sampling line 123. Along line 123 are a
17 device 119, for measuring gas flow from the hood, and various auxiliary
18 devices.

19 A third sampling line 124, which also includes auxiliary devices, is
20 also installed. It receives ambient air from intake 117 for calibrating and
21 verifying the accuracy of the system.

22 The auxiliary devices in lines 122, 123 and 124 include compressor or
23 compressors 127 to provide a positive flow of offgas from hood 110, hood

1 118 and intake 117 through these lines. Pressure relief valves 128 prevent
2 build-up of excessive pressure in the lines. Drying systems 133 remove
3 entrained water and water vapor from offgas. Valves 134 or other devices
4 control flow of air and/or other gas from the hoods or intake into a
5 measurement system that includes sample analysis line 125.

6 On line 125 are found a restriction 142 which throttles gas flow to
7 create positive pressure in the measurement system and a device 143
8 which detects moisture or condensate in offgas or ambient gas flow. Device
9 144 measures carbon dioxide content in the offgas. Device 145 measures
10 gas pressure, device 146 measures gas temperature. Device 113
11 measures oxygen content in the offgas, and an outlet 116 discharges
12 sample air to the atmosphere.

13 Other elements of the measurement system include devices 152 and
14 153 which measure gas flow to the first and second zones of the tank, as
15 well as devices 112 and 120 for measuring the dissolved oxygen content of
16 the wastewater in the first and second zones.

17 The control system includes a controller 114, for measurement and
18 process control. It automatically executes control logic for both zones of the
19 tank. Connections 115 transmit measured values from the measurement
20 system to the controller and control signals from the controller to valves 90
21 and 95. Interface device 154 can assist in entry of constants and control
22 parameters into the system and displays measured and calculated data.

1 In the embodiment illustrated in Figure 3 each portion of the tank
2 constitutes a separate zone of operation, with the ability to measure and
3 control gas flow in each of the zones independently of the other zone. It is
4 usual, but not mandatory, that the tank will be configured as a plug flow
5 tank so that the flow of wastewater under treatment will be from the first
6 zone into the second zone, with or without other intervening zones. In this
7 embodiment requirements control values for each zone are calculated
8 independently of all considerations of previous or subsequent zones.

9 Similarly, DO control values for each zone are calculated independently of
10 all considerations of previous or subsequent zones. This is true whether or
11 not the calculations for each zone are performed sequentially or
12 simultaneously in a single controller or the calculations are performed in a
13 separate controller for each zone.

14 From a combination of the requirements control values and DO
15 control values for each zone, controller 114 establishes separate and
16 varying gas rates and corresponding control signals that will satisfy the
17 varying needs for oxygen in the respective zones. These signals are sent
18 to gas flow regulating devices 90 and 95 as required to meet such needs.

19 Additional embodiments implicit in the arrangement identified in
20 Figure 3 and employing the principles illustrated therein would include more
21 than two separate control zones in a single plug flow tank, or two or more
22 separate control zones in parallel plug flow tanks. The principles illustrated
23 by Figure 3 are further independent of whether or not baffles or tank walls
24 separate control zones.

1 **Figure 4**

2 The embodiment of Figure 4 will be preferred for many wastewater
3 treatment plants where economic considerations, pre-existing tank
4 configurations, and/or process considerations dictate a system simpler than
5 that shown in Figure 3 but more complex than that shown in Figures 1 and
6 2. In common with Figure 1, the embodiment of Figure 4 has a single tank
7 170 conducting a suspended growth aeration process, inlet 228 and outlet
8 229, respectively, for wastewater entry and mixed liquor discharge, and one
9 location for sampling gas escaping from the tank, but two locations for
10 determining DO levels.

11 In and around tank 170 are components of a gas supply system.
12 Among these are plural devices 174 of any suitable type for introducing
13 oxygen-containing gas bubbles into the wastewater, a source of gas 175,
14 which is shown as a pipe but could be another device, and a gas flow
15 regulating device 180.

16 In common with Figure 1, this control system includes sampling lines
17 177 and 178 and analysis line 179. These lines include or are connected
18 with various items of auxiliary devices or measuring apparatus, discussed
19 below.

20 Lines 177 and 178 include such auxiliary devices as compressors 199
21 to provide a positive flow of gas, pressure relief valves 200 to prevent build-
22 up of excessive pressure, drying systems 205 to remove entrained water
23 and water vapor, and valve 206 or some other device to control the

1 direction of gas and/or air flow from various locations, to the atmosphere
2 and/or to the measurement apparatus in proper sequence. Line 178 also
3 includes an ambient air intake 189, for calibrating and verifying the
4 accuracy of the measurement apparatus.

5 Among the elements of the measuring apparatus in and around the
6 tank are a device 176, for measuring wastewater temperature, and a gas
7 collection member, e.g., a hood 182, connected to sampling line 177, for
8 collecting gas escaping from the tank. Also, line 177 includes a device 183,
9 for measuring gas flow from the hood.

10 Arranged along analysis line 179 are device 215 which detects
11 moisture or condensate in offgas or ambient gas flow, device 218 which
12 measures gas temperature, device 217 which measures gas pressure,
13 device 216 which measures carbon dioxide content in the off-gas, device
14 185 which measures oxygen content in offgas, restriction 214 which
15 throttles gas flow to create positive pressure in the measurement
16 apparatus, and an outlet port 188 which discharges sample gas to the
17 atmosphere.

18 Other elements of the measurement apparatus include device 222
19 that measures flow from gas source 175 to tank 170 and two DO sensors
20 184 and 192. These measure the DO level of the wastewater in upstream
21 and downstream portions of the tank, respectively.

22 Additional elements of the embodiment of the control system include
23 a controller 186, for automatically executing control logic, and connections

1 187, for transmitting measured values to the controller and control signals
2 from the controller to valve 180. Interface Device 226 is provided to display
3 measured and calculated data and to facilitate entry of constants and
4 control parameters for operating the system.

5 It is often important to maintain the DO level in a particular portion of
6 a tank at a fixed or substantially uniform level to ensure that the wastewater
7 oxygen demands have been satisfied. Generally, but not necessarily, DO
8 level is monitored for this purpose downstream of the point of entry of the
9 wastewater, near where the wastewater flows out of the tank. The DO level
10 in this portion of the tank can be critical for determination of DO control
11 values. Thus, Figure 4 shows the downstream DO sensor, device 192, at
12 or near the downstream end of the tank.

13 However, it is often true, especially in a plug flow operation, that the
14 downstream end of the tank is not the optimum place for gathering data on
15 the oxygen requirements of the process to determine requirements control
16 values. Thus, in this embodiment, other components of the control system
17 of the invention are located elsewhere, typically but not necessarily near the
18 location where wastewater flows into the tank.

19 Accordingly, in the present embodiment, hood 182 and related control
20 components are positioned near wastewater inlet 228, upstream of the
21 location in the tank at which it is desired to maintain a specific fixed or
22 substantially uniform oxygen level. Sensors used to determine
23 requirements control values, e.g., device 185 to measure the oxygen
24 content in the offgas and device 184 to measure DO at this location, are

1 located in a way that they can determine the oxygen requirements at the
2 upstream location.

3 Controller 186 uses data from devices 184 and 185 at the upstream
4 location to calculate the varying requirements control values that will satisfy
5 the need for varying amounts of oxygen to support metabolism of waste.
6 The controller also calculates, based on data from DO sensor 192, varying
7 DO control values necessary to maintain specified target DO levels in the
8 downstream location. These requirements and DO control values are
9 combined in the controller to establish varying total gas flow rates for the
10 tank as a whole that are estimated to be necessary for satisfying steady
11 state and dynamic needs for oxygen to support metabolism and DO
12 control needs. Such gas flow rates are used by the controller to establish
13 varying control signals sent to control valve 180 when and as needed to
14 satisfy such needs.

15 An alternate mode of operation for the apparatus shown in Figure 4 is
16 to utilize the upstream location for determining both DO control values and
17 requirements control values for the entire tank. In this configuration,
18 referred to as "cascade control", DO control values are calculated from the
19 dissolved oxygen level measured at the upstream location by device 184.
20 The DO target level used for determining DO control values for the
21 upstream location is calculated from DO levels measured at the
22 downstream location by device 192. A mathematical function can be used
23 to establish a relationship between downstream DO levels and upstream
24 DO target levels. For example, one may use a ratio of one level to the
25 other, or a ratio of (a) the difference between a downstream target DO level

1 and downstream measured DO levels to (b) the upstream target level.
2 Alternatively, the upstream DO target level may be increased or decreased
3 as the measured downstream DO level falls below or above the
4 downstream target DO level. From such functions, a controller may
5 calculate DO control values to combine with requirements control values to
6 control gas flow into the tank.

7 Further embodiments include, among others, a number of tanks, each
8 with a single point of gas flow control, utilizing a single controller and a
9 single set of devices for measuring the characteristics of the gas leaving the
10 process. Each of these tanks may or may not have a separate set of
11 devices for determining downstream DO control values and/or upstream
12 requirements control values.

13 **Figure 5**

14 Figure 5 is a schematic software and process flow sheet. Within the
15 data entry functions area, located at the upper left corner of the flow sheet,
16 are three parallelograms identifying data to be entered into and stored in
17 the memory of controllers when the system is set up. This data may be
18 updated from time to time if necessary. Within the control logic functions
19 area is a series of rectangular boxes and parallelograms that identify
20 operations that are performed by the controllers.

21 A first parallelogram located in the upper left corner of the control
22 logic functions area identifies inputs of data into the controller from sensors
23 in the control system, e.g., wastewater temperature measuring device 5,

1 gas flow measuring device 11 and oxygen content measuring device 13 of
2 the Figure 1 embodiment. Based on continuous or periodic measurements
3 taken by whatever sensors may be included and active in that embodiment
4 or other embodiments of the control system, the controller generates, on a
5 continuing, e.g., repetitive, basis, varying control values, e.g., requirements
6 control values, DO control values and such other control values as may be
7 desired.

8 Another parallelogram in the lower right corner of the control logic
9 functions area represents repetitive outputs of the controller to gas quantity
10 regulating apparatus, such as one or more of the valves 1 illustrated in
11 Figure 1. Such controller outputs represent control inputs from the control
12 system to the aeration process, causing a valve or other device, e.g., valve
13 1 of Figure 1, to act in response to such inputs and change or maintain the
14 quantity of gas introduced into the wastewater.

15 In the present control system embodiments, the controller has a built
16 in or operator selectable waiting time. This is an increment of time that may
17 be selected to elapse between repeated controller outputs and based for
18 example on anticipated or observed system response time(s), and/or the
19 degree of fineness of control desired and/or other considerations. See the
20 box above the third and fourth columns in the control logic functions area.
21 These increments may be of any suitable duration.

22 Embodiments such as that illustrated by Figure 5 include provision for
23 correcting, over a selected response time, such errors as may exist in the
24 DO level of the wastewater, thus tending to move the DO level back toward

1 a target value. In such embodiments, waiting time is preferably coordinated
2 with system response time so that the entire response time substantially
3 coincides with or occurs within the waiting time. However, commonly used
4 continuous output controls (such as Proportional-Integral-Derivative) may
5 be employed with or without waiting time without departing from the
6 fundamental principles of the invention.

7 Persons skilled in the art will understand that the order of a number of
8 the functions in the flow sheet may be rearranged, and that the control
9 system can nevertheless operate successfully. Furthermore, persons skilled
10 in the art will readily perceive that it is possible to design embodiments that
11 involve modification or elimination of some steps in the flow sheet without
12 departing from the fundamental principles of the invention.

13 In the foregoing preferred embodiments, the varying control values, or
14 components thereof, remain correlative with the varying amounts of oxygen
15 consumption by the biological process. That is, there is an established
16 quantitative relation, present in the control system, between requirements
17 control values and such consumption. This quantitative relation is applied
18 repeatedly by the control system in the determination of changing
19 requirements control values during a given rise and/or fall of such
20 consumption detected by the system. Such repetition preferably occurs
21 during a plurality of consecutive determinations of requirements control
22 values during the given rise and/or fall. Still more preferably, repetition in
23 plural consecutive determinations occurs during a plurality of consecutive
24 rises and falls. However, the above-mentioned quantitative relation may be
25 changed intentionally from time to time, such as by an operator and/or by

1 the control system itself, e.g., by an adaptive controller, to refine the match
2 which the system makes between requirements control values and oxygen
3 consumption.

4 **Additional Embodiments**

5 There are a number of additional embodiments which may optionally
6 be practiced in conjunction with the embodiments described above, or with
7 other embodiments of the invention. These include, by way of example and
8 not limitation:

9 1) Measuring O₂ concentration as % of volume or % of mass directly in an
10 offgas stream.

11 2) Adding C₀₂ concentration as % of volume or % of mass measurement
12 to the sample gas stream to increase accuracy of determination of offgas
13 oxygen concentration.

14 3) Establishment of DO control values related to gas flow required to
15 account for DO error based on the equation:

$$\frac{\Delta DO \cdot V}{t_c} = \frac{1}{aF \cdot \theta' \cdot C'} = \text{Gas Flow Required}$$

18 Where:

20 ΔDO = DO_{target} - DO_{actual}

21 V = Control volume, may refer to the complete tank or part of it

1 t_c = Time constant to establish the time set to correct actual DO
2 to Target DO

3 αF = Apparent alpha value, combined effect of wastewater
4 characteristics (α), and gas supply system condition (F), on gas
5 supply system ability to transfer oxygen to wastewater

6 θ' = Correction factor for effect of wastewater temperature on gas
7 supply system ability to transfer oxygen to wastewater
8 $\theta' = \theta^{(T-20)}$, where T is wastewater temperature

9 θ = Arrhenius coefficient for wastewater temperature correction
10 factor to account for wastewater temperature effect on oxygen
11 transfer

12 T = Wastewater Temperature

13 C' = Correction factor to account for effect of DO levels or Target
14 DO levels on the ability of gas supply system to transfer oxygen
15 to wastewater

16 $C' = \underline{C'_{\infty f}} - \underline{DO}$

17 $C'_{\infty 20}$

18 4) Periodically drawing a sample of ambient air and using the results to
19 correct for drift and calibration error in the offgas O₂ concentration and CO₂
20 concentration measurement devices.

21 5) Using a positive displacement compressor on the sample gas line to
22 maintain constant sample time latency and insure constant sample flow
23 rate.

1 6) Using pressure and temperature measurement on the sample gas line
2 or hood exhaust line to convert volumetric flow rate to mass flow rate.

3 7) Using a direct mass flow measurement device to measure mass
4 directly.

5 8) Adding multiple reactors and hoods to be sampled and wherein control
6 action is determined in a specific sequence by a single controller.

7 9) Measuring barometric pressure to increase the accuracy of the
8 calculations.

9 10) Calculating and displaying values derived from measured data that
10 are of use in monitoring reactor performance, including for example:

11 aF , K_{La} , airflow/diffuser, SOTR and OUR.

12 11) Plotting and archiving performance data over time.

13 12) Providing alarming for excursions in process parameters to indicate
14 equipment failure, process problems, and maintenance requirements.

15 13) With ambient calibration systems or multiple tank systems, adding
16 solenoid valves to vent gas and allow continuous sample compressor
17 operation.

18 14) Integrating the control of a single reactor with the control of a
19 complete system and with control of blowers to coordinate all control
20 actions and minimize perturbations.

1 15) Using a single modulated blower for each reactor instead of multiple
2 reactors drawing gas from a common distribution system.

3 16) Applying empirically derived constants to the oxygen-containing gas
4 flows to accelerate or decelerate system responses or offset site-specific
5 conditions; for example such constants may be applied to flows determined
6 from DO control values if process considerations require the response time
7 to differ from theoretical values, or to correct short term sags in DO levels.

8 **Preferred Embodiment of Control System Calculations**

9 Further discussion which follows includes a preferred embodiment of
10 bases for calculations that are useful in generating control values and are
11 thus useful in constructing appropriate software or code for the controller.
12 This discussion describes a preferred embodiment of how to control a
13 diffused air aeration gas supply system in such a way so that:

14 1. Requirements control values are developed in order to satisfy the
15 oxygen requirements of the biological treatment process, and

16 2. DO control values are developed in order to maintain a pre-
17 established DO concentration at selected locations in the aeration
18 basin.

19 A number of process variables and conditions are considered and
20 manipulated to allow identification of gas supply system operating settings
21 that will achieve the established objectives.

1 The basic structure of the preferred control strategy proposed
2 comprises the following steps:

- 3 1. Determination of actual oxygen consumption (Oxygen Uptake Rate
4 or OUR) in the tanks, tank, tank zone or other container of wastewater
5 under treatment, also referred to as the reactor;
- 6 2. Determination of oxygen transfer characteristics that will affect the
7 ability of the gas supply system to supply oxygen to the process;
- 8 3. Establishment of oxygen requirements for the process;
- 9 4. Establishment of required gas supply system operating conditions
10 to satisfy the requirements established; and
- 11 5. Adjustment of gas supply system operating conditions to
12 established conditions.

13 Thus, the control system includes elements and devices capable of
14 performing these steps. These steps, and the underlying basis for the
15 method by which this embodiment performs them, will be described in
16 greater detail below.

17 Determination Of Actual Oxygen Consumption In The Reactor (OUR)

18 The Oxygen Uptake Rate (OUR) of mixed liquor is determined using
19 off-gas analysis and typically is useful in establishing requirements control

1 values within the control system. This methodology allows using at least a
2 portion of the activated sludge reactor itself as a respirometer, with
3 performance on a continuing basis of gas phase mass balances of oxygen
4 across a selected control volume, to determine the amount of oxygen
5 introduced by the gas supply system, and with performance on a continuing
6 basis of liquid phase mass balance of oxygen across the same control
7 volume, to identify how much of the oxygen introduced by the gas supply
8 system is being consumed by microorganisms in the wastewater.

9 The control volume could be the entire liquid-containing volume of the
10 reactor, but is conveniently a selected small portion of the total volume
11 selected to provide the most useful or convenient information for control
12 purposes. By way of illustration and not limitation, consider a plug flow tank
13 measuring about 20 meters (width) by 100 meters (length) by 5 meters
14 (water depth) or more. In such a tank, one might select a control volume
15 which, by virtue of its location in the tank, would be reasonably
16 representative of the process performance of the reactor. For example, one
17 might choose a position centered on the longitudinal centerline of the tank,
18 about 24 meters from the tank upstream end and, being about 1.2 meters
19 (wide) by 2.4 meters (long) horizontally and extending vertically throughout
20 the depth of the wastewater in the tank.

21 Liquid phase mass balance involves a variety of physical, chemical
22 and biochemical processes that take place simultaneously. Dissolved
23 oxygen enters and leaves the control volume as a consequence of water
24 flowing in and out of this volume. Because water may contain oxygen (in
25 the form of dissolved oxygen), such water entering the control volume will

1 represent an input of oxygen to the control volume, and water exiting the
2 control volume, with whatever DO concentration is present in it, will
3 represent an oxygen output. Other oxygen inputs may have to be
4 considered, such as those due to operation of aeration devices, or, in the
5 simplest example, by charging pure oxygen into the control volume.
6 Biological activity in the biomass responsible for treatment of the
7 wastewater uses up some or all of the oxygen available in the tank. When
8 establishing a liquid phase mass balance of oxygen across a control
9 volume, oxygen consumed by the biomass will no longer be present in the
10 liquid and may therefore be considered as an oxygen output from the
11 control volume. Any other sources of oxygen output should also be
12 considered when formulating this mass balance, for example oxygen output
13 sources such as those due to reactions that may occur, such as following
14 the addition of an oxidizing agent. However, in diffused air aeration plants,
15 oxygen input due to transfer occurring in the liquid surface-atmosphere
16 interface in open air aeration tanks is assumed to be a negligible fraction of
17 the transfer taking place below the liquid surface.

18 Thus, this embodiment provides a mass balance formulation in which
19 oxygen input and output via water flowing into and out of the control
20 volume, oxygen input due to gas supply system operation, and oxygen
21 output from oxygen consumption by the biomass and dissolved oxygen
22 inventory in the control volume need to be considered.

23 In those cases where the total oxygen inputs to the control volume
24 are greater than the total oxygen outputs, a net increase of oxygen occurs
25 in the control volume, and an increase in the total oxygen inventory in the

1 control volume is observed. Similarly, when the total oxygen outputs are
2 greater than the total oxygen inputs, a decrease in the total oxygen
3 inventory will be observed.

4 When this mass balance is conducted on a control volume over a
5 certain period of time, a given term in the mass balance relationship
6 (whether it be, for example, an oxygen input or an oxygen output to or from
7 the control volume) may be determined if all the remaining terms are of
8 known value.

9 Under these circumstances, absent any other oxygen input or output
10 source, biomass oxygen consumption may be determined if the oxygen
11 input by the gas supply system, the net oxygen input (of positive or negative
12 value) due to oxygen contained in incoming and outgoing control volume
13 water flows and the net change (of positive or negative value) in control
14 volume of dissolved oxygen inventory are known or measured.

15 Whenever these principles are applied to a full depth section or
16 portion of an aeration tank located at a significant distance from the tank
17 vertical walls, one may picture the control volume as a limited portion of the
18 tank volume having imaginary vertical boundary surfaces that run all the
19 way from the bottom of the tank to the liquid surface. No water enters
20 through the bottom (tank bottom) or top of the control volume, and all water
21 flows enter or leave the control volume through its side boundaries.
22 Assuming the control volume embraces a relatively small portion of the
23 horizontal dimensions of the tank, whereby the dissolved oxygen levels
24 would be expected to vary little from one side of the volume to the other, no

1 significant changes in the oxygen content of the control volume would be
2 expected to occur as a result of imbalance between incoming and outgoing
3 water flows, so these flows may be treated as the same. All water flows
4 enter the control volume from regions just outside an imaginary boundary
5 and all the outgoing flows depart from regions just inside such a boundary.
6 Because this boundary does not physically exist, it may be assumed that
7 liquid characteristics at both sides of the boundary are the same. If this
8 assumption is applied to dissolved oxygen content in the liquid, it may be
9 assumed that dissolved oxygen at both sides of the boundary is the same.
10 If the boundaries of the control volume do correspond or partially
11 correspond with physical boundaries, e.g., a tank wall with a small opening
12 or an communicating pipe, this assumption may not be applicable.

13 In those cases where the assumption as to imaginary boundaries is
14 applicable, the net oxygen input associated with liquid flowing into the
15 control volume and liquid flowing out of the control volume is of the same
16 value under steady state volume conditions and, thus, dissolved oxygen
17 concentrations in incoming and outgoing flows are the same. Therefore, the
18 net oxygen input due to interchange of liquid between the control volume
19 and the rest of the aeration tank is zero.

20 Under these circumstances, the only remaining terms in the mass
21 balance are the oxygen input due to gas supply system oxygen transfer, the
22 oxygen output associated with oxygen consumption by the biomass, and
23 the net change (of positive or negative value) in the control volume
24 dissolved oxygen inventory.

1 Whenever arrangements are made so that conditions for the
2 application of the described procedure are met, the amount of oxygen being
3 consumed by the biomass over a certain period of time may be determined
4 from the gas supply system oxygen transfer and the net change in control
5 volume dissolved oxygen inventory.

6 The net change in control volume dissolved oxygen inventory may be
7 derived from dissolved oxygen measurements at the beginning and end of
8 the time period during which a mass balance is performed and the control
9 volume.

10 The determination of the Oxygen Transfer of the gas supply system is
11 done with a second mass balance on oxygen (gas phase mass balance) for
12 the selected control volume. This mass balance is based on the idea that, in
13 the absence of any other gas phase oxygen inputs and outputs, whatever
14 amount of oxygen is depleted from the gas is equivalent to the oxygen
15 dissolved into the liquid (oxygen transferred to the liquid).

16 Therefore, oxygen transfer may be determined from analysis of gas
17 entering and gas leaving the system.

18 One approach to this task is to measure the oxygen entering the
19 system in the aeration gas and the oxygen leaving the system in the offgas
20 by measuring the gas flow and oxygen content of the incoming gas and the
21 gas flow and oxygen content in the offgas.

1 Another approach to this task involves assuming that both the
2 Incoming volumetric gas flows and outgoing volumetric offgas flows are of
3 the same value as a consequence of no net changes of gas volume in the
4 system (gas volume in the system remains constant with time).

5 A suitable way of determining the amount of oxygen present in both
6 the incoming and the outgoing gas streams could be to compare the
7 oxygen present in each gas stream with other components present in each
8 gas stream that remain constant through the process. By way of example, if
9 the aeration gas used contains a certain portion of gas A that is not
10 transferred to the liquid and does not react with the tank contents (inert),
11 then both the incoming gas stream and the outgoing gas streams would
12 show the same content of gas A. Gas A is conserved during the process.

13 In order to do so, it may be necessary to measure the carbon dioxide
14 and water vapor content of the incoming and outgoing gas streams.

15 Oxygen depletion in the gas phase or oxygen transfer to the liquid
16 phase may then be expressed as a percentage reduction in oxygen content
17 in the gas stream by comparing the difference between the molar ratios of
18 oxygen to inerts in the incoming and outgoing streams to the molar ratio of
19 oxygen to inerts in the incoming stream.

20 Whenever this approach is followed, the percentage oxygen transfer
21 determined (Oxygen Transfer Efficiency) may be combined with oxygen
22 input rate data to determine Oxygen Transfer Rate. By way of example, the
23 mass of oxygen transferred may be determined from the percentage

1 oxygen transfer observed and the mass flow of oxygen introduced into the
2 system. In many instances it may be convenient to express mass balance
3 equations in terms of rate units (oxygen transfer rate, oxygen uptake rate,
4 and net oxygen inventory change rate) instead of mass units.

5 Exemplary Variables Involved

9 OI_{tmb} = Oxygen inventory in a control volume at the end of the time
10 period during which a liquid phase oxygen mass balance is
11 performed

12 OTE = Oxygen Transfer Efficiency

13 OTR = Oxygen Transfer Rate

14 OUR = Mixed Liquor Oxygen Uptake Rate

15 $O_{2\text{conc}}$ = Concentration of Oxygen in Oxygen containing gas

16 Q = Oxygen containing gas volumetric flow into the control volume
17 t_{mb} = Time constant set to establish the period of time during which
18 a liquid phase oxygen mass balance is performed

19 V = Volume, may relate to the complete tank or part of it

20 Values associated with these variables within the control system may be
21 stored in or developed by the control system with the aid of data within the
22 system or acquired from external sources.

1 Determination Of Oxygen Transfer Characteristics

2 The information gathered during the calculations conducted to
3 determine OUR may also be used to assess the oxygen transfer
4 characteristics of the system studied if appropriate data are available. In
5 order to do so, some relationship between the Oxygen Transfer of a gas
6 supply system in process conditions and the Oxygen Transfer of the same
7 system under known conditions may be used.

8 In the aeration industry, oxygen transfer of gas supply systems and
9 devices is commonly expressed in relation to a set of reference operating
10 conditions to allow comparison of different equipment under equivalent
11 conditions. This is due to the fact that gas supply system oxygen transfer
12 depends on factors such as ambient conditions (barometric pressure and
13 water temperature amongst others), water characteristics (composition,
14 etc.) and dissolved oxygen concentration in the aeration basin that would
15 make data from different aeration devices very hard to compare unless
16 operating under similar (if not exactly the same) conditions.

17 When comparing oxygen transfer of a gas supply system operating
18 under process conditions with oxygen transfer of the same system under
19 reference conditions (Standard Conditions), a number of correction factors
20 are preferably introduced to account for the different effect of different
21 operating conditions on system performance.

22 In addition, tests at reference conditions are usually conducted on
23 new gas supply systems, so in those cases where oxygen transfer of a gas

1 supply system may be influenced by gas supply system condition (new
2 versus used systems), another correction factor can be introduced to
3 account for the effect of gas supply system condition on oxygen transfer.

4

5 Correction factors for ambient conditions such as water temperature,
6 barometric pressure and water temperature have been documented in the
7 literature and widely accepted and extensively used in the past.

8

9 However, due to the difficulty of establishing a relationship between
10 wastewater characteristics and composition and its effect on oxygen
11 transfer, no widely accepted correction factors have been established for
12 the determination of oxygen transfer of a gas supply system in wastewater
13 compared to its performance under reference conditions, e.g., in potable
water.

14

15 If ambient condition correction factors are used in combination with
16 the values of the parameters involved in the above-mentioned corrections,
17 some of which may require measuring and others of which may be
18 assumed, a relationship between the oxygen transfer of the gas supply
19 system as measured in process conditions and the oxygen transfer of the
20 same gas supply system under standard conditions could be developed in
21 which all terms in the relationship would be known (measured or calculated)
22 except the effects of (a) wastewater characteristics and (b) gas supply
23 system condition. Therefore, even if the individual values of these two
24 parameters were not identified, their combined effect could be determined.
25 Once this effect has been determined (apparent alpha), a relationship
between standard conditions gas supply system oxygen transfer and

1 process conditions gas supply system oxygen transfer, where all correction
2 factors are known or established, could be developed and be useful in
3 establishing gas supply system performance control values.

4 Determination of the oxygen transfer characteristics of the gas supply
5 system and mixed liquor of the process involves measuring both the
6 wastewater temperature in the control volume and the Dissolved Oxygen in
7 the mixed liquor. Although $C^*_{\infty f}$ can be calculated from measured values
8 such as Barometric Pressure, Wastewater Temperature and Salinity
9 Correction factor β , its small variation suggests the possibility of using built
10 in relationships, meaning that the control system could operate successfully
11 on the basis of fixed values for $C^*_{\infty f}$ stored or introduced temporarily into the
12 control system. Thus, a control system built according to this embodiment
13 of this invention will include one or more DO (dissolved oxygen) sensors
14 and one or more temperature sensors, as will be discussed below in
15 conjunction with the accompanying drawings.

16 Exemplary Variables Involved

17 α = Effect of wastewater characteristics on gas supply system
18 ability to transfer oxygen into wastewater
19 αF = Apparent alpha value, combined effect of wastewater
20 characteristics (α), and gas supply system condition (F), on gas
21 supply system ability to transfer oxygen to wastewater
22 β = Correction factor for the effect of salinity on dissolved oxygen
23 saturation concentration
24 $C^*_{\infty 20}$ = Dissolved oxygen saturation concentration at 20°C, 1 atm

$C^*_{\infty f}$ = Dissolved oxygen saturation concentration in field conditions

= Mixed liquor dissolved oxygen

K_{La} = Apparent volumetric mass transfer coefficient

F = Effect of gas supply system condition (often associated to diffuser fouling/aging) on gas supply system ability to transfer oxygen

OTR = Oxygen Transfer Rate

P = Barometric Pressure

SOTR = Oxygen Transfer Rate at Standard Conditions (20°C, 1 atm, 0 DO, clean water)

θ' = Correction factor for effect of wastewater temperature on gas supply system ability to transfer oxygen to wastewater, $\theta' = \theta^{(T-20)}$, where T is wastewater temperature

θ = Arrhenius coefficient for wastewater temperature correction factor to account for wastewater temperature effect on oxygen transfer

T = Wastewater Temperature

Values associated with these variables within the control system may be stored in or developed by the control system with the aid of data within the system or acquired from external sources

Establishment Of Oxygen Requirements

As previously mentioned, in the present embodiment of the invention, the approach taken in the control system for determining the oxygen requirements of the biological process the system at any point in time

1 includes satisfying the oxygen requirements of the biological treatment
2 process and maintaining a preestablished or target DO concentration at
3 one or more selected locations in the process mixed liquor.

4 Although determination of the oxygen requirement of the biological
5 treatment process has been discussed above, the present embodiment
6 also determines the oxygen required to keep the process at a
7 preestablished DO concentration as a function of the actual process
8 conditions with respect to the preestablished conditions (DO target level).
9 Whenever actual process conditions match the preestablished target
10 conditions, both objectives of the control strategy are met. The process is
11 taking up oxygen at the rate at which it is being supplied and operates at
12 the desired dissolved oxygen level.

13 However, if the actual process conditions differ from the target
14 conditions, a difference between the actual DO concentration at the
15 selected control point in the mixed liquor and the target DO concentration at
16 that same control point is observed. This may happen because the DO in
17 the aeration basin is higher than the target value or lower than the target
18 value. In both cases, DO control values should be developed and corrective
19 actions implemented to return DO levels to target DO levels. If only the
20 higher or lower amount of oxygen required by a change in biomass
21 consumption of oxygen were supplied, the difference observed as to the
22 DO level in the process versus the DO target level would remain present.
23 An additional amount of oxygen should be supplied when process DO is
24 lower than target DO, and a lesser total oxygen supply than that required by

1 biomass consumption should be supplied when process DO is higher than
2 target DO.

3 The needed increment of increased or decreased oxygen supply,
4 above or below that required to meet current biomass requirements may be
5 determined by establishing a relationship between observed process
6 conditions and target process conditions. This may be done by considering
7 the dissolved oxygen inventory in a selected control volume around the
8 target DO control location. More particularly, the control system determines
9 how much dissolved oxygen would be present in the mixed liquor if the
10 target DO were achieved and how much DO is actually present in the same
11 volume. The difference between these two quantities, positive or negative,
12 is then added or subtracted by the control system from the amount of
13 oxygen required for biomass consumption.

14 Because oxygen requirements are usually expressed as rates, the
15 result of this DO inventory, i.e., the total mass of oxygen to be added or
16 subtracted from biomass requirements, will usually be converted into an
17 oxygen supply rate required to return DO to the target value over a selected
18 time period. Introduction of a time parameter establishes the speed at which
19 the DO level will be returned to the target value.

20 Target DO refers to a selected level of DO which the operator wishes
21 to maintain at a selected control location and t_c refers to a time constant, the
22 period of time in which it is desired to return DO to the target DO level.
23 Δ DO refers to the difference between the target DO and the mixed liquor

1 DO (dissolved oxygen content of the wastewater) for the selected control
2 location.

3 Exemplary Variables Involved

4 DO = Mixed liquor dissolved oxygen
5 Δ DO = Difference between target dissolved oxygen concentration
6 and actual dissolved oxygen concentration at a selected
7 location
8 DO_{target} = Target DO concentration for a selected location
9 t_c = Time constant to establish the time set to correct actual DO to
10 Target DO
11 V = Volume, may relate to the complete tank or part of it

12 Values associated with these variables within the control system may be
13 stored in or developed by the control system with the aid of data within the
14 system or acquired from external sources.

15 Determination Of Gas Supply System Required Operating Conditions

16 Once the oxygen requirements needed to meet established goals is
17 determined, the relationship between gas supply system oxygen transfer in
18 process conditions and gas supply system oxygen transfer in standard
19 conditions, developed as described above, is used by the control system to
20 determine the standard conditions oxygen supply required by the process.

1 Data available on standard condition performance of the gas supply
2 system, which data may be stored in or developed by the control system
3 with the aid of data within the system or acquired from external sources,
4 may then be useful in determining gas supply system operating conditions
5 and performance control values required to achieve the desired oxygen
6 supply.

7 Exemplary Variables Involved

8 The following is a key to certain expressions used in the above
9 description and in the measurement and calculation of process variables:

10 α = Effect of wastewater characteristics on gas supply system
11 ability to transfer oxygen into wastewater

12 αF = Apparent alpha value, combined effect of wastewater
13 characteristics (α), and gas supply system condition (F), on gas
14 supply system ability to transfer oxygen to wastewater

15 β = Correction factor for the effect of salinity on dissolved oxygen
16 saturation concentration

17 $C^*_{\alpha 20}$ = Dissolved oxygen saturation concentration at 20°C, 1 atm

18 $C^*_{\alpha f}$ = Dissolved oxygen saturation concentration in field conditions

19 DO = Mixed liquor dissolved oxygen

20 DO_{target} = Target DO concentration for a selected location

21 F = Effect of gas supply system condition (often associated to
22 diffuser fouling/aging) on gas supply system ability to transfer
23 oxygen

24 OUR = Mixed Liquor Oxygen Uptake Rate

1 Q = Oxygen containing gas volumetric flow into the control volume
2 ROTR = Total Required Oxygen Transfer Rate under process
3 conditions
4 SOTR = Oxygen Transfer Rate at Standard Conditions (20°C, 1 atm, 0
5 DO, clean water)
6 θ' = Correction factor for effect of wastewater temperature on gas
7 supply system ability to transfer oxygen to wastewater, $\theta' = \theta^{(T-20)}$,
8 where T is wastewater temperature
9 θ = Arrhenius coefficient for wastewater temperature correction
10 factor to account for wastewater temperature effect on oxygen
11 transfer
12 T = Wastewater Temperature

13 Values associated with these variables within the control system may be
14 stored in or developed by the control system with the aid of data within the
15 system or acquired from external sources.

16 Adjustment Of Gas Supply System Operating Conditions

17 All of the steps described in previous sections cover the different
18 procedures and methods used to establish the aeration operating
19 conditions required to achieve the control goals established.

20 Once individual SOTR values applicable to one or more control
21 volumes and/or complete tanks are established, the control system uses
22 this information to adjust gas supply system parameters and devices, using
23 the correlation between gas supply system performance at process

1 conditions and at standard conditions. In most cases, gas supply system
2 operating conditions can be defined as a function of individual/total gas
3 flows to each control zone/complete tank.

4 **Definitions**

5 “Adjust” or “adjustment” refers to: modifying data from a measuring
6 device or control signals from a controller, including for example a change
7 in magnitude and/or conversion to a different form. These terms also refer
8 to altering one or more biological process parameters and altering one or
9 more conditions of some part of the biological process equipment and/or of
10 the control system. Usually, such altering is in response to some indication
11 of need, which may be a changing need for oxygen-containing gas, such as
12 the need for gas consumed in the biological process, and/or the need for
13 gas to change a DO level and/or the need for gas occasioned by changes
14 in gas supply system performance. Such altering may occur on a
15 continuous or intermittent basis. In some instances, alteration can occur in
16 such a way that the full amount of corrective action required to meet one or
17 more needs occurs immediately, when the control system senses the need.
18 In other instances, alteration can occur over a period of time, in increments.
19 For incremental alterations, it is not possible to state for all situations the
20 absolute minimum proportion of the corrective action that must be applied
21 in the first and subsequent increments. Biological treatment plants can vary
22 widely in their time of response to corrective actions. When the invention is
23 embodied in ways that involve continuing but incremental alteration, system
24 wait times can vary widely. However, alterations can occur in increments
25 representing a small proportion of the total corrective action desired when

1 wait times are short and/or plant response time is long. Conversely, larger
2 increments may be required when wait times are long and/or plant
3 response times are short. Armed with this understanding and their
4 experience with plant operations, persons skilled in the art can determine,
5 without undue experimentation, what proportion of the total corrective
6 action should be applied in the respective increments, so that there will be a
7 sufficient amount of corrective action per increment to prevent changing
8 needs from frequently or seriously out-running the control system.

9 "Aerobic biological process" means any of a variety of biological
10 processes, one or more portions of which are supported, at least in part by
11 the introduction of oxygen containing gas into wastewater in order to create
12 an aerobic environment. Prominent examples of these processes exist in a
13 wide variety of continuous and discontinuous configurations of the activated
14 sludge process involving a variety of flow regimes. Examples include plug
15 flow, complete mix and step feed aeration. Submerged aerated filters and
16 other batch processes are contemplated in which the wastewater is aerated
17 for all or a portion of the operation cycle for each batch.

18 "Amount", as applied to any given tangible or intangible thing,
19 including without limitation materials, data and signals, refers to a quantity
20 of that thing or a quantity relationship between that thing and another
21 tangible or intangible thing. Such quantity or relationship may be
22 expressed in any unit or units or without units. For example, an absolute
23 quantity may be expressed in units of, e.g., mass or volume. A relative
24 quantity may be expressed, e.g., as units of the given thing per unit time
25 (rate) or per unit volume or mass of another thing, or as a ratio between

1 different things which, e.g., are expressed in the same kinds of units, so
2 that the nature of the units may be ignored.

3 "Approximate" means that there is a degree of correlation between
4 values which, whether perfect or imperfect, is sufficient to be useful in
5 controlling a wastewater aeration process in accordance with the invention.

6 "Biological process" means any wastewater treatment process which,
7 at least in part, involves the metabolism by bacterial action of waste
8 material dissolved and/or suspended in wastewater, that encompasses,
9 among others, one or a combination of aerobic, anoxic, and anaerobic
10 steps or processes.

11 "Composition", as applied to a gas, refers to the identities of at least a
12 portion of the gases in a mixture of two or more different gases, or to the
13 relative amounts of two or more gases in such a mixture, or to the amount
14 of a single gas in such a mixture.

15 "Connected with" means having a tangible or intangible operational
16 connection, whether direct or indirect, including such tangible forms of
17 connection as dedicated wires, electric power lines and wiring systems,
18 intranet or internet connections, telephone lines, fiber-optic cables,
19 connections on circuit boards and pneumatic signaling lines, and such
20 intangible forms of connections as radio waves, laser and other light
21 beams, and sound waves, by which control system resources such as data,
22 control signals or outputs, control inputs and code may pass between
23 cooperating components of the control system, e.g., measuring devices,

1 controllers and flow regulating devices, whether such components are
2 located close to or distant from one another.

3

4 "Consumption of oxygen ... in the biological process" refers to oxygen
5 that is consumed, e.g., by bacteria or other means, in removing from the
6 wastewater and/or in otherwise acceptably altering, e.g., by metabolism
7 and/or by other mechanisms, carbonaceous, and/or nitrogenous and/or
8 other forms of waste; this language is intended to distinguish process
9 oxygen needs from deficiencies and excesses in the supply of oxygen to
10 the wastewater which manifest themselves as decreases and increases in
11 the DO level of the wastewater.

12 "Continuing", for example as in the exercise of continuing control or
13 the taking of continuing measurements, refers to actions taken on a
14 continuous basis or on an intermittent but repetitive, including a periodic or
15 irregularly repeating basis.

16 A "controller" is any device which is or includes one or more logic
17 devices, and is able, whether alone or in combination with one or more
18 other devices, to interpret values correlative with one or more parameters of
19 the biological process and to establish control values.

20 The controller may for example be at least in part, including wholly,
21 one or more mechanical devices and/or one or more electrical and/or
22 electronic devices. Thus, the logic of the controller may for example reside
23 at least in part in one or more mechanical relationships in mechanical

1 devices, electrical relationships in electrical and/or electronic devices,
2 and/or in any combination of the foregoing.

3 The controller preferably includes or at least has access to
4 appropriate software or code to interpret data on process conditions
5 gathered from measurement apparatus and establish the control values. In
6 a preferred embodiment, the logic resides at least in part, which may
7 include wholly, in one or more elements of code temporarily present or
8 stored in one or more co- or remotely- located programmed or
9 programmable devices.

10 Controllers used in the invention may be specialized units of limited
11 but sufficient computing capacity, or may be a general- or special-purpose
12 computer or computers of considerable computing capacity. The controller
13 is preferably capable of executing basic control instructions (e.g., Boolean
14 logic and four function math) such as those commonly available through
15 (but not limited to) computer or personal computer (PC) based control
16 platforms, programmable logic controller (PLC) based control platforms, or
17 distributed control systems (DCS) based control platforms. Proportional,
18 proportional-integral (PI) and proportional-integral-derivative (PID)
19 controllers may be used. See, e.g., "Process Instruments and Controls
20 Handbook", 3d Ed., McGraw Hill.

21 The controllers may also include memory devices, as well as
22 comparators, other devices and/or code that adjust, refine, correct,
23 condition or otherwise assist by performing auxiliary functions, such as
24 tuning the control system and/or processing data, control values and control

1 signals. Thus, adaptive (self- or auto- tuning) or non-adaptive controllers
2 may be used.

3 In effect, the controller defines, for the varying amounts of biological
4 consumption of oxygen that occur in the process, control values, or
5 components of control values, that change in response to, while remaining
6 correlative with, such varying amounts of oxygen consumption. Put
7 differently, the controller generates varying control values which have, or
8 which respectively include at least one component that has, on a continuing
9 basis, an at least approximate quantitative relationship with the varying
10 amounts of oxygen consumed by the biological process.

11 Control values generated by the controller, with or without
12 intermediate adjustment, are useful for acting on the process, or on items
13 such as valves or other control elements associated with it, to alter or
14 maintain operation of the process in a way that generally limits or minimizes
15 deviation of one or more process variables from desired performance, for
16 example from established set points. Control values of more than one type,
17 e.g., respectively corresponding with more than one process need, may be
18 combined within the controller, e.g., to generate a single control signal
19 involving plural components. Optionally, control values that respectively
20 represent different process needs may be generated but kept separate
21 within the controller and used to issue separate control signals to different
22 control elements.

23 Correlative with", as applied to a relationship between first and
24 second values, means that, regardless of whether or not they are

1 numerically equal or precisely related, there is at least an approximate
2 quantitative relationship between them, a sufficient degree of relatedness
3 so that they or at least one of them can serve as a practical basis for control
4 over the process. The magnitude of one or more of the values may be
5 affected by its inclusion of one or more parameters, usually small enough to
6 be ignored, that are not part of the relationship on which the correlation is
7 based. In embodiments of the invention in which a first value is correlative
8 with but not numerically similar to a second value, the first value may be
9 functionally related to the second in such a way that the first may be used
10 as an at least approximate indicator of the other. Any useful functional or
11 other type of relationship between the values will suffice. The relationship
12 may take any useful form. For example, one value may be directly
13 proportional to the second. Or the first may be related to the second by a
14 fixed or variable difference. Or the first may be related to the second
15 through an equation or table of values. Values of all kinds are included, for
16 example Oxygen Transfer Rate vs. Gas Flow, and Oxygen Transfer
17 Efficiency vs. Gas Flow. In the case of control values, "correlative with"
18 preferably refers to a relation between (a) an applied control value applied
19 by the system in relation to a particular process control needs, e.g., process
20 oxygen needs, DO level control needs, performance control needs or a
21 combination of process control needs and (b) a reference control value
22 which would adjust operation of the biological process in a way that would
23 precisely satisfy the particular need or needs; in such relation, the applied
24 control value, whether applied in one or a plurality of increments,
25 approximates the reference control value. The adequacy of this
26 approximation will be expressed in conventional usage as a percentage
27 difference between the control value and the reference value, said

1 difference being plus or minus 20%, more preferably plus or minus 10%,
2 still more preferably plus or minus 5%, and most preferably plus or minus
3 3%. Notwithstanding this conventional usage, as the reference value nears
4 the upper and lower bounds of the useable range it may be more
5 convenient or more accurate to express the adequacy of this approximation
6 as a finite difference, e. g. plus or minus 0.10 ppm or plus or minus 25 cubic
7 meters per hour.

8 “DO control values” or “dissolved oxygen control values” refer to
9 measured and calculated parameters correlative with the amount of oxygen
10 required to move a DO level (including positive oxygen or zero oxygen
11 conditions) observed in the process to or toward a target DO level.

12 “Gas collection member” means a device comprising a confined
13 chamber for receiving from wastewater and substantially isolating from the
14 atmosphere at least a portion of the gas bubbles that have been released
15 into wastewater by a gas supply system and have traveled upward in the
16 wastewater for at least a portion of its depth but have not been dissolved in
17 the wastewater. A typical but non-limiting example would be a hood,
18 rectangular in plan view and triangular in transverse cross-section, having
19 an open bottom; except for inlets and outlets associated with its control
20 function, it is otherwise gas tight and is equipped throughout the periphery
21 of its lower edges with floats to support it at the surface of wastewater. Gas
22 collection members need not however be located at the wastewater
23 surface, since they can perform their receiving and isolating functions if
24 positioned beneath the surface or if positioned above the surface and

1 provided with dependent skirts extending, throughout their periphery, in a
2 direction down toward and preferably to a position beneath the surface.

3 “Gas supply system” includes any bubble-forming device or devices
4 of widely varying type, shape and size that is/are suitable for transferring
5 the oxygen of an oxygen containing gas to wastewater in the context of a
6 biological treatment process, for example area release fine bubble
7 diffusers, draft tube aerators, mechanical aerators, brush aerators and
8 coarse bubble diffusers, along with the necessary accessory equipment to
9 support the operation of the bubble forming device or devices and deliver
10 the gas thereto, including gas supply conduits, manifolds, support stands,
11 downcomers, yard piping, valves, filters, positive displacement
12 compressors, turbo-compressors, or centrifugal blowers and related
13 compressor/blower control and gas flow control devices. Illustrative area
14 release fine bubble diffusers include those in the form of tubes, disks,
15 domes and sheets, whether of elastomeric, ceramic or fibrous material.
16 Examples of coarse bubble diffusers include hood, nozzle, orifice, valve
17 and shear devices.

18 “Indicative” refers to the quality of indicating a given value numerically
19 equally or, if not numerically equally, at least through a functional or other
20 relationship, such indication being a precise value so far as can be
21 determined by observation or calculation from the data available in the
22 system or, if not such a precise value, deviating from the precise value by
23 an amount insufficient, taking into account the intended use of the
24 indication, to destroy its usefulness for effecting control over the biological

1 process. In a preferred embodiment, the indication is within +/- 20%, or +/-
2 10%, or +/- 5% or +/- 3% of said precise value.

3 "In response to" refers to direct and indirect stimulation of an action or
4 condition by another action or condition; for example a control element acts
5 in response to a control signal when such action is a direct or indirect result
6 of the control signal, whether the signal is received directly or indirectly from
7 a controller with or without modification or conversion to a different form.

8 "Mixed Liquor" refers to the contents of a tank comprising at least
9 wastewater and biomass.

10 "Oxygen-containing gas" includes any gas, including mixtures of
11 gases with or without entrained or dissolved vapors, for example air,
12 oxygen, ozone, any other gas and mixtures of any of these, that is suitable
13 to support an aerobic biological process or process step for the treatment of
14 wastewater, such as a suspended growth aeration process and preferably a
15 process that includes one or more activated sludge processing steps.

16 "Oxygen Uptake Rate" (OUR) refers to the time rate of consumption
17 of oxygen in the wastewater, and includes components such as biomass
18 oxygen consumption, other forms of oxygen consumption, chemical
19 reactions, and other factors.

20 "Performance parameters" refer to measured, calculated, or pre-
21 determined values that are correlative with changes in performance or
22 efficiency of any device or process in the system.

1 "Provide" or "Providing" means making available in any manner for
2 use in the control system for any useful period. For example, as applied to
3 code or data, the definition includes making same available from within or
4 without the system, from a source at or remote from the site at which the
5 biological process is conducted, by generating same in the system, and/or
6 by manually inputting same into the system, and/or by storage of same in
7 the system, whether or not the storage location is within the system and
8 whether or not storage is brief or long term, with or without being updated
9 from time to time.

10 "Repetitive" means repeated at a time interval of any length which is
11 useful in effecting control of an aeration operation in the context of the
12 invention, for example, at intervals of up to about 8 hours, more preferably
13 up to about 1 hour and still more preferably up to about 5 minutes. These
14 intervals may be as short as a very small fraction of a second, e.g., about
15 0.01 second or more, preferably about 10 seconds or more and more
16 preferably about 30 seconds or more.

17 "Requirements control values" refers to measured and calculated
18 parameters correlative with the oxygen required to satisfy the usage of
19 oxygen in the biological process. These may include but are not limited to
20 all factors related to oxygen uptake rate (OUR) in both steady state and
21 non-steady state conditions.

22 "Suspended growth aeration process" means an aerobic biological
23 process in which oxygen containing gas usually assists in mixing the

1 wastewater, and still more preferably, assists in maintaining the bacteria in
2 suspension.

3 "Tank" refers to one or more suitable natural and/or man-made water
4 impounds which may be of widely varying type, shape and size. Thus, the
5 tank or tanks may be earthen- or plastic-lined, but are preferably of steel or
6 concrete and are of any suitable shape when viewed in plan view or vertical
7 section. For example, the tanks may have a circular, annular, oval, square
8 or elongated rectangular shape in plan view. The term tank also applies to
9 a section of a tank that has been segregated from one or more other
10 portions of that tank by a baffle and/or other form of length divider so that
11 the segregated section responds substantially independently of the other
12 section or sections to control inputs. Preferred are tanks in which their
13 dimensions in the direction of wastewater flow, whether in a straight line or
14 not (L), are greater than their dimensions perpendicular to such direction
15 (W), in which L/W may, e.g., be greater than 3, 5, 10 or 15, such as tanks of
16 annular or elongated rectangular shape. Preferably, at least the aerobic
17 portions of the tanks will be equipped with any suitable gas supply system.

18 "Values" are representations of (a) quantities, expressed in any
19 suitable unit or combination of units, such as units of mass, volume,
20 pressure, time, electrical potential, resistance or other units, or expressed
21 as unitless numbers, or of (b) conditions, e.g., "on", "off", "above", "below",
22 "equal to" and others. The results of measurements are usually expressed
23 as values.

1 “Wastewater” refers to the wastewater undergoing treatment at any
2 stage in a biological process, encompassing among others raw wastewater,
3 wastewater after preliminary treatment, mixed liquor and other mixtures of
4 wastewater and biomass.